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DETERMINATION OF THE MAXIMUM CONTROL FORCES AND

ATTAINABLE QUICKNESS IN THE OPERATION OF AIRPLANE CONTROLS

By Heinrich Hertel

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DETERMINATION OF THE MAXIMUM CONTROL FORCES AND ATTAINABLE QUICKNESS IN THE OPERATION OF AIRPLANE CONTROLS.*

By Heinrich Hertel.

This report is intended to furnish bases for load assumptions in the designing of airplane controls. The maximum control forces and quickness of operation are determined. The maximum forces for a strong pilot with normal arrangement of the controls is taken as 1.25 times the mean value obtained from tests with twelve persons.

For the quickest operation of the controls, the maximum forces are not much greater than those found in the tests. It is possible not only to maintain these forces, but even to make slight deflections of the controls at this load. Fatigue from long and frequent operation of the controls, with only short periods of rest, caused only a slight reduction in the maximum forces.

The maximum quickness of operation of the elevator and aileron controls was found to be about 200 cm/s (78.7 in./sec.), the variations in the test results being very slight. The maximum quickness of operation of the rudder control is less and depends on the maximum control force, the quickness dropping from

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a maximum of about 60 cm/s (23.6 in./sec.) for a very small control force to about 20 cm/s (7.87 in./sec.) for a maximum foot pressure of 150 kg (330 lb.). All the tests show a systematic relation of the maximum physical forces required for the different operations.

I. Object of the Investigation

The necessary bases were to be established for the determination of new load assumptions for calculating the dimensions of airplane controls. Tests with a number of persons were expected to show the maximum forces that a man of average strength can exert on the control stick in operating the elevator and ailerons and also on the rudder bar. The effect of fatigue, of duration and of the nature (static or dynamic) of the force, as also the condition of the test subject (with or without belt) required investigation. The best values of the control forces to be adopted as the basis for determining the dimensions of the controls were to be obtained from the mean values of the maximum forces expended by all the persons tested.

In the dynamic tests, the maximum quickness of operation under various control forces was measured, whereby the control force increased from zero to a maximum. A knowledge of this quickness is necessary for determining the maximum control forces.

II. Test Program (Cf. Table I)

1. Stick and Rudder-Bar Control

The tests were first tried with 12 persons, chiefly athletic engineers and airplane pilots. The number was then reduced to 8, after it was found that the results differed but little with normal subjects. One of these subjects exhibited particularly well-balanced physical powers, so that several supplementary tests were made with this individual, whom we shall designate as the "chief subject."

The 38 main tests (with 12 or 8 persons) are indicated in Table I. The notation used in the table will be retained in the rest of this report.

E, elevator control,

r, right hand,

l, left hand,

P, pull,

p, push,

f, free (without belt),

a, attached (with belt),

t, tired (fatigued),

A, aileron control,

R, rudder control,

w, wheel control,

q, quickness,

s, slow,

j, jerk.

TABLE I. Test Program

Series	I	Ia	II	IIIs	IIIj	
Max. force	Static, brief		Static	Dynamic		Quick-ness
	Free	Attached	Tired(free)	Slow push	Jerk	
Elevator	ErPf	ErPa	ErPt			
		Erpa	Erpt			
	ElPf	ElPa	ElPt			
		Elpa	Elpt		EbPj	q E
	EbPf	EbPa	EbPt	Ebps		
Ailerons	ArPf	ArPa	ArPt			
	Arpf	Arpa			Arpj	q A
	AlPf	Alpa	AlPt			
	Alpf	Alpa				
	Abf	Aba	Abt			
Rudder (r)	R		Rt			q R
Wheel		wbra*				
		wbla*				

*These tests were made with four different positions of the hands on the wheel (horizontal, vertical, and at ±45°).

2. Wheel Control

The strength tests with a handwheel were made in 1927 with ten other subjects, but the results are included in this report. The tests are designated in Table I by the sumbols w b r a and w b l a.

III. Test Outfit

A pilot's seat (Junkers A 35), a control stick and a rudder bar, corresponding to those on a medium-sized airplane, were mounted on a wooden substructure as shown in Figure 1. The pilot's seat was provided with a safety belt (including shoulder strap) for making the tests of series Ia.

In Figure 1, a is the pilot's seat, b the control stick, and c the rudder bar. Of the six control cables, the aileron control d, the elevator control e, and both rudder controls f are visible. The springs g, used in the dynamic tests, are attached to the aileron control cable. An electric stop watch h was used to measure the time. The electric circuit was closed at the initial or final position of the control stick by connecting the latter with one of the rails k. The watch ran while the circuit was open, i.e., during the motion of the stick.

The control cables, corresponding to the arrangement on an airplane, were given the vertical direction by passing them around ball-bearing pulleys, so they could be loaded in the

tests of the series I, II, and IIIs by hanging weights on them.

In the dynamic tests (series IIIj) with the quickness measurement, the force exerted by the stick or rudder bar should increase from almost zero in the initial position of rest to its maximum value in the final position. Weights could not be used in the dynamic tests, because the great acceleration produced by the quick operation of the controls would have necessitated special devices. The load was therefore applied by means of 1 to 5 spiral springs (g), which were calibrated before the tests. Moreover, after the installation of the springs, the control stick was pulled back slowly with a dynamometer, so that the force exerted was known for every position of the stick.

The duration of the motion was measured by means of an electric stop watch. On moving the stick from its position of rest the circuit of the watch was opened, thus starting the hand. The circuit was again closed by another contact at the end of the motion, thereby stopping the watch. The time was measured to 0.01 second. In the dynamic rudder-bar tests, the time for a 4 cm (1.57 in.) movement was measured by the electric stop watch.

Since the tests with each subject covered several days, in order to avoid excessive fatigue, the physical condition of the subject was determined before each test by means of a hand-pressure dynamometer commonly used in psychotechnics. The test was continued only when the result agreed well with the preceding

days. This instrument was also used immediately before and after each test, in order to determine the fatiguing effect of the test on the subject.

2. Wheel Control

A control wheel of $d = 36$ cm (14.2 in.) outside diameter was mounted on a horizontal axle. The control cables descended vertically on each side of the cable drum, which had a radius of 5 cm (1.97 in.), and were fastened to the floor with the interpolation of dynamometers. A Junkers A 35 pilot's seat was mounted in front of the control wheel in the normal relative position on an airplane. The subject braced his feet against a beam which replaced the rudder bar. If it is assumed that equal and opposite forces R are exerted by the two hands on the rim of the wheel, then

$$R = \frac{Dr}{d} = D \frac{5}{36} = \frac{1}{7.2} D,$$

D being the dynamometer reading.

IV. Performance of Tests

Series I (static tests).- In the stick tests (elevator and ailerons) Ef, Ea, Af, and Aa. the loads on the control cables were increased as fast as possible from the initial load of 20 kg (44 lb.) with 5 kg (11 lb.) increments up to the maximum weight the subject could hold on the control stick and

make short slow motions of the latter against the force exerted by the weight. For the rudder control, the initial load was 50 kg (110 lb.). Increments of 25 kg (55 lb.) were added as rapidly as possible up to the maximum load. In the handwheel tests w b a, a dynamometer was actuated by the torsional moment on the rim of the wheel, so that the force could be read. In the test series I f, the subject was free to move in the seat, not being restrained by any belt or shoulder strap. In series Ia, the subject was secured by an ordinary safety belt and shoulder strap.

Series II (fatigue tests).- a) The load increments were added as shown in Table II. Each control-stick load was held five minutes by the test subject. After each test there was an interval of three minutes.

TABLE II. Load Increments

Tests	Initial load	Load increments
ErPt, Erpt, ElPt, Elpt	10 kg (22 lb.)	2 kg (4.4 lb.)
EbPt, Ebpt	20 " (44 ")	5 " (11.0 ")
ArPt, AlPt	1 " (2.2 ")	1 " (2.2 ")
Apt	2 " (4.4 ")	2 " (4.4 ")
Rt	20 " (44 ")	10 " (22.0 ")

b) The IIa tests were supplemented by endurance tests of four subjects in pushing the elevator controls with both hands, a record being made in each instance of the length of time the subject could hold the load. The load on the stick was reduced 10 kg (22 lb.) at a time from the maximum static load in series I down to a load that the subject could hold for five minutes or more.

Series III (dynamic tests).- a) Test E b p s of series IIIs served to determine the maximum force which the subject could exert in pushing the stick slowly for a considerable distance, so that his position was unfavorable at the beginning of the push, due to the slight flexure of the arms.

b) In tests E b P j and A r p j of series IIIj, it was the task of the test subject to move the control stick at the greatest possible speed, from a position of rest fixed by a stop, through a distance of 20 cm (7.87 in.) to its final position, which was also fixed by a stop. The stick was jerked. The load on the end of the control cables (corresponding to the control-surface loading) was applied by stretching the spiral springs in actuating the controls. In test E b P j the force on the stick was increased from a preliminary tension of 5 kg (11 lb.) to a final force of 32 kg (70 lb.) for each spring. The tests were made with 1 to 5 parallel springs. In test A r p j the preliminary tension was 1 kg (2.2 lb.) and the final force was 9 kg (19.8 lb.) per spring. In test QR the preliminary ten-

sion was 5 kg (11 lb.) and the final force was 30 kg (66 lb.) per spring. The individual tests were repeated until the minimum time was determined which the subject required for making the motion.

<u>Series IV (supplementary tests)</u>.- These tests are described in Section V,9.

V. Test Results

1. General Remarks

a) The same subjects were used for all the control-stick and rudder-bar tests. The handwheel tests, however, were tried with ten other subjects.

b) The relative arrangement of the pilot's seat and the controls was like the usual one on airplanes. The movements of the controls and the maximum-force measurements on the control stick, in the tests designated as "attached" (i.e., with safety belt), were always made from the neutral or vertical position of the stick. Since the subject, due to being strapped in, could not change his position, the maximum forces were affected by the size of body and length of arms and legs of the different subjects. In the "attached" tests, the subject could not assume the best position for operating the controls but, on the other hand, the belt furnished a secure hold for the subject. This is especially important in pulling with both hands, since he would otherwise pull himself forward without exerting all his strength on the control stick.

c) In the case of the "free" (i.e., without safety belt), elevator tests, an exception was made to the rule that the motion of the control stick should start from the neutral vertical position. In order to determine the effect of flexing the arms on the maximum force, the "free" tests were made with extended arms, while the arms were so flexed in the "attached" tests that the stick was vertical.

d) The handwheel tests were successively made with four different positions of the hands: vertical, horizontal, 45° to the right, and 45° to the left with respect to the diameter of the wheel.

e) In the static tests with the control stick and rudder bar, the controls were not only held at the maximum load, but were moved short distances to and fro. The motion was so slow, however, as to produce no accelerations of importance.

f) Of the test subjects, Nos. 2 and 10 of the stick and rudder-bar tests, as likewise No. 4 of the handwheel test, were left-handed. The results obtained with the two hands were therefore interchanged in tabulating.

g) The results of the stick and rudder-bar tests obtained with subject No. 12, a 42-year-old engineer, were intended to supply information regarding very low maximum values. They varied so much, however, that they were omitted from the report.

h) Subject No. 1 gave exceptionally uniform results, even in repetitions, so that they were accorded particular consider-

ation in the analysis. The test results of No. 1, who will be designated as the chief subject, are plotted in Figures 2,4 and 5.

i) The test results are given in Tables III to VII. The tables also record the mean values and proportionality factors which are used as average values in the following description. The average values were formed from the values for the chief subject, the mean values, and the maximum values. The justification of this procedure will be shown farther on.

k) The most probable maximum forces (1.25 times the mean values obtained in the static tests with 12 subjects), for a strong pilot with normal controls, are as follows:

	"Attached"	"Free"
Elevator:		
Two-hand push	125 kg (275 lb.)	125 kg (275 lb.)
" " pull	125 " (275 ")	85 " (187 ")*
One-hand pull or push	65 " (143 ")	85 " (187 ")**
Ailerons, stick control:		
Two-hand operation	33 " (73 ")	50 " (110 ")
One-hand push	27 " (60 ")	45 " (99 ")
" " pull	20 " (44 ")	45 " (99 ")
Ailerons, wheel control:		
Two-hand operation, each	35 " (77 ")	-
Rudder bar:		
One-foot push	270 " (595 ")	270 " (595 ")

*At the maximum value the body was lifted from the seat. This value was actually measured, instead of being taken as 1.25 times the mean value.
**Length of pilot's arm enabled operation with arm extended.

TABLE III. Description of Test Subjects

No.	Vocation	Interest in sports	Age years	Weight kg	Height cm	Spread cm
I	Engineer	Little	23	72	176	168
II	Stud. eng.	Much	25	75	177	182
III	Engineer	Average	29	74	164	152
IV	"	None	37	74	168	152
V	"	Average	27	73	175	162
VI	Stud. eng.	None	26	75	180	163
VII	Engineer	"	28	68	179	156
VIII	Aviator	Average	27	78	180	168
IX	"	"	26	76	177	157
X	"	"	24	74	181	173
XI	Engineer	"	23	78	177	160

TABLE VIII. Fatigue Tests*

Test	Max. control force- (fatigue)	Hand force (before)	Hand force (after)	Max. control force (static) (before)	Max. control force (static) (after)	% loss of hand force	% loss of control force (static)
2-hand elevator pull (fatigue) EbPt	40	55	46	124	105	16.4	15.4
Ditto	40	54	45	125	105	16.7	16.6
2-hand elevator push (fatigue) Ebpt	40	55	48	130	110	12.8	15.4
Rt-hand aileron control (fatigue) Arbt	7	55	46	18	15	16.4	16.7

The following divisions 2 to 11, correspond to the principal lines in Tables III to VII.

2. Maximum value; chief subject; mean value

a) Table IX shows by what per cent of the minimum, maximum and average of all similar tests, the values for the chief subject, as likewise the maximum values, exceed the mean values.

*For Tables IV to VII, see end of report.

TABLE IX. Comparison with the Mean Values

			% above mean value		
			Minimum	Maximum	Average
Elevator	Static "	Chief subject Max. value	-3 16	23 36	11 25
	Fatigued "	Chief subject Max. value	20 20	55 55	38 40
Ailerons	Static "	Chief subject Max. value	4 10	35 35	18 24
	Fatigued "	Chief subject Max. value	13 13	42 42	27 27
Rudder	Static Fatigued	Max. value " "			26 20
Wheel	Static	Max. value	20	30	25

The relatively large excess of the maximum values over the mean values in the fatigue tests is attributable to the fact that, in the case of different subjects who show especially great discrepancies between the static and endurance tests, fatigue is accompanied by aversion.

b) Table IX shows that, in all static tests, the maximum values average about 25% above the mean values, while the static values for the chief subject are about 15% greater than the mean values. The mean values, raised by about 25%, may be regarded as equalized maximum values from which accidental peaks have been eliminated.

3. "Attached" and "Free"

a) In what follows, average values (derived from the values for the chief subject, the mean values and the maximum val-

ues) will be given for the ratio of the values obtained when the subject is strapped in or "attached" and when he is "free" (not strapped in).

b) Elevator, static.- In pulling with one hand, the average value is reduced about 15% by the subject being strapped in, which, in this case, necessitates flexure of the arm in the neutral position. In pulling with both hands, the free body is pulled forward when the force exerted on the stick exceeds the weight of the body, so that the pull on the stick cannot be further increased. The two-handed pull on the stick can be increased about 38% on the average by strapping the subject in, despite the flexing of the arms. Static-push tests were not tried for the "free" condition.

c) Ailerons, static.- The body is forced into an unfavorable position with respect to the stick by being strapped in, so that the values are considerably greater when the subjects are left free. The effect differs for pulling, pushing and operating with both hands, but is the same for the right and left hand. The average reduction from being strapped in is about 59% for a one-handed pull, 42% for a one-handed push, and 37% for a two-handed operation. It is less in the latter case because the body lacks the support of the belt.

4. Pull ("attached" and "free"). Push ("attached" and "free")

a) Elevator (excepting two-handed pull and push).- In the tests with the chief subject, the values for pulling and pushing are alike for all the static tests, but in the dynamic tests the pull is increased 9%. Some of the mean and maximum values were found to be a little higher for pulling, namely, about 6% in static tests and 9% in fatigue tests.

b) The differences between pulling and pushing were likewise smaller when the subject was "free," and greater when he was "attached." As compared with pushing, the pulling values averaged about 30% less when the subject was fastened and about 1% more when he was free.

5. Right-handed; Left-handed; Two-handed

a) Elevator "attached."- The differences in the values for the right and left hand are not important in the static and fatigue tests, their sums being nearly equal to the values for two-handed operation. On the average, the right hand was found to be about 4% stronger than the left hand in the static tests and about 2% stronger in the fatigue tests. The force exerted by both hands together averaged about 3% less than the sum of the right-hand and left-hand forces in the static tests and about 2% more than their sum in the fatigue tests.

b) Elevator "free."- In pushing, the results did not differ much from the "attached" tests. In pulling, there was likewise not much difference between the right-hand and left-hand tests. The values for the two-handed pull were 43% less than the sum of the one-handed pulls, due to the above-mentioned lifting of the body.

c) Ailerons.- For like manner of operation the results of the static tests differed only 4% between the right and left hand. The sum of the right-hand pull and the left-hand push, however, was found to equal the sum of the right-hand push and left-hand pull for both "free" and "attached" tests, but the values for two-handed operation were 31% smaller "attached" and 46% smaller "free" than the corresponding sums. This reduction in the values for two-handed operation was due to the fact that the support of the body against turning was inadequate, especially in the "free" condition. In contrast with all the other tests, the aileron fatigue tests (pull without belt) showed the left hand to be 18% weaker than the right hand.

d) Wheel control.- The mean values in Table VII show that the maximum forces can be exerted when the line connecting the hands is an oblique diameter of the wheel. For a connecting line ascending from right to left at an angle of 45°, the maximum force is produced by a left turn while, for a connecting line ascending 45° from left to right, the maximum force is produced by a right turn. In both cases the hand forces amount to

about 35 kg (77 lb.). The maximum force is about 25% less in the opposite direction. The forces for the horizontal or vertical position of the line connecting the hands are alike and are the mean between the values for the favorable and unfavorable directions of turning at the 45° position of the hands.

6. Static Force. Fatigue Tests

The static values for the elevator are 2.5 to 3.65, an average of 2.85 times as great; for the ailerons 4.6 to 8, an average of 6.2 times as great; and for the rudder an average of 3.5 times as great as the fatigue values. The large reduction factors of 2.85, 3.5, and 6.2 are due to the specifications for the fatigue tests. After the proof, however, of the regularity of the loss of power from fatigue, the dependence of the reduction factor on the fatigue specifications can be easily determined by a supplementary test (Cf. 7).

7. Duration. Maximum Force

In series IIb for supplementing the results mentioned in 6, four subjects were tested at various elevator control forces (push, "attached") to determine how long they could hold out. The results are shown in Figure 3. During the first minute there was a decrease of about 30% in the maximum force. Then the endurance time increased greatly with diminishing load.

8. Fatigue Tests with Dynamometer

The dynamometric measurement of the hand force furnished a criterion for the fatigue. The measurement was made before each test, in order to determine whether the subject was in normal physical condition, and was repeated after each test, to show how much the test had reduced the strength of the subject. The results are given in Table VI.

In every test, the mean of the initial and of the final values was obtained for eleven subjects. The average of the mean initial values, for all the tests with the right hand, was found to be 54.4 kg (120 lb.) with a variation of only ±0.2 kg (0.44 lb.) in the mean values. For the left hand, it was 48.6 kg (107 lb.) with a variation of only 0.8 to 1.4 kg (1.8 to 3.1 lb.).

The fatigue was uniformly greater for the left hand than for the right, the loss in strength averaging 11% for the elevator in pulling and 5.5% in pushing. For the ailerons it averaged only 2.5%. In the operation of the aileron controls, the measured fatigue in the static test is very small, despite the reduction factor of 6.2 in the fatigue tests. The great contrast between 12.3% in the two-hand pull and only 3.5% in the two-hand push did not appear in the tests with the chief subject, who showed greater fatigue from pushing than from pulling.

9. Fatigue Test with Dynamometer
Reduction of Control Force

In all the fatigue tests, the fatigue of the stressed hand was determined by the dynamometer and showed that, with the exception of the "two-hand push," considerable fatigue could be determined numerically. Supplementary tests showed the diminution in the maximum static force corresponding to the dynamometrically measured hand fatigue. Moreover, in tests with one-handed operation of the controls, it was found possible, by dynamometric measurements of the stressed and of the unstressed hand, to determine how much the loss in strength was due to a locally limited fatiguing of the stressed member and how much it was due to the general exhaustion of the whole body. These tests were made only with the chief subject and gave the results shown in Table VIII, which may be briefly summarized as follows:

a) Dynamometric measurements showed the perfectly uniform reduction in the hand force, the same as the control-force measurements. The excellence of the dynamometric measurements was also confirmed by the fact that the initial values in all the tests (on three consecutive days) were just the same. The force reduction averaged 15.4% for the elevator on the dynamometer and 15.5% on the control stick. The aileron control (only one test) gave a force reduction of 15.2% on the dynamometer and 16.6% on the control stick.

b) The fatigue was felt first in the stressed members. The slight fatigue of the unstressed hand with respect to the dynamometer and control stick could not be definitely determined by the small number of tests.

c) Since the actual reduction in the maximum control force corresponded to the fatigue subsequently shown by the dynamometer, and the fatigue tests, made under severe conditions, yielded average strength reductions of only 15% for the most fatiguing operations, it followed that any considerable reduction in the maximum control forces through fatigue could not be taken into account.

10. Maximum Control Force

The maximum force produced by quick operation of the controls ("jerking") depended largely on the manner of operation, which was not easy to determine subsequently, since only the total duration of the motion of the control stick was measured. In the operation of the elevator control, the two-hand "free" pull was chosen for determining the dynamically attainable maximum forces on the control stick, because the maximum spring forces could thus be attained. Since the nearly neutral control column was operated by a quick jerk, the controls and the moving parts of the operator himself acquired considerable kinetic energy during the first part of the motion, which was then partially absorbed by the further stretching of the springs. Dur-

ing the pull, therefore, the maximum force on the control stick did not equal the maximum force of the spring. It was, instead, equal to the force of the spring at the moment the sontrol stick reached the forward limit of its motion when it was so great that the control stick recoiled somewhat. The test results show that, in the most unfavorable case, the maximum forces exerted on the elevator controls may, when the stick is jerked quickly, exceed the measured maximum static forces, due to the effect of inertia. In contrast with the conditions on the elevator, the effect of the accelerated masses was only slight on the aileron controls (push, right hand, "free"), so that for the ailerons, the differences between the maximum dynamic and static forces were only slight (averaging about 2%).

11. Quickness of Operation

The maximum quickness of operation was experimentally determined in the motion of the control stick from the neutral position through a distance of 20 cm (7.87 in.) with a uniform increase in the stick force from about zero to various maximum loads. The maximum quickness is nearly independent of the attainable maximum force, provided the stick can move at least 20 cm (7.87 in.). Contrary to expectations, a slight increase in the quickness of operation at the maximum force of the springs occurred with several subjects and even in the mean values. The two-hand "free" pull of the elevator averaged $v_E = 191$ cm/s

(6.26 ft./sec.), and the repeatedly attained maximum value $v_{max\ E}$ = 210 cm/s (6.89 ft./sec.). The right-hand "free" push of the aileron control averaged v_A = 178 cm/s (5.84 ft./sec.), whereby the value $v_{max\ A}$ = 200 cm/s (6.56 ft./sec.) was repeatedly attained. Briefly it may be said that, nearly up to the maximum final force on the control stick, the maximum quickness of operation, for a 20 cm (7.87 in.) motion of the elevator and aileron controls, averaged about 200 cm/s (6.56 ft./sec.) (Figs. 4 and 5), making the time 0.1 second for a motion of 20 cm (7.87 in.).*

The maximum quickness of operating the rudder bar depended on the maximum control force. The bar was pushed from its neutral position by the right foot. With the unloaded rudder bar the maximum quickness of v_{max} = 67 cm/s (2.2 ft./sec.) was attained by the principal subject, the mean value being v_{max} = 60 cm/s (about 2 ft./sec.). The quickness decreased with increasing maximum control force from v_{max} = 60 cm/s (2 ft./sec.) to v = 20 cm/s (7.87 in./sec.) at a maximum foot pressure of 150 kg (330 lb.)

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*In the British A.C.A. Reports and Memoranda No. 282 (Experiments on the Possible Rate at which a Pilot can Pull Back the Control Column in an Aeroplane), July, 1916, the maximum quickness of the elevator pull was 160 cm/s (5.25 ft./sec.), likewise independent of the load. The 200 cm/s for the elevator and aileron controls in the present report are therefore 25% greater. The difference is probably due to the fact that, in the English investigation, the motion of the control stick was nearly twice as great. Moreover, in the present tests a very large number of measurements (up to 20 per test subject and per loading stage) were made and the maximum value of all the measurements are included in the analysis.

12. "Unforced" Maximum Forces

In most of the tests it was the duty of the subject to exert his full strength. Only in the wheel-control tests w b r a and w b l a he was not to make any unusual exertion. These tests are designated as "unforced" maximum forces in Table VII. These forces were found for the most favorable positions of the hands on the wheel and the most favorable direction of rotation of the wheel. The mean value of the "unforced" maximum force for all the subjects is about 2/3 of the maximum attainable force.

The following designations apply to the corresponding numbers in Tables IV and V.

1	Mean value Maximum value	
2	Maximum value: chief subject: mean value.	
3	Attached: free	Chief subject Mean value Max. value
4	Pull attached: push attached	Chief subject Mean value Max. value
5	Attached: right hand, left hand, both hands	Chief subject Mean value Max. value
6	Static: fatigue	Chief subject Mean value Max. value

TABLE IV. Test Results for Elevator Control (cont.)
(Control-stick forces in kilograms)

No.	Dynamic		Fatigued					
	Two-handed		Right-handed		Left-handed		Two-handed	
	Slow push Ebps	Jerk EbPj	Pull ErPt	Push Erpt	Pull ElPt	Push Elpt	Pull EbPt	Push Ebpt
I	85	128	24	22	22	22	45	45
II	80	160	24	18	24	18	35	30
III	60	160	20	10	18	12	40	30
IV	65	160	16	12	16	12	35	30
V	60	160	16	14	14	14	35	30
VI	60	160	15	10	15	12	35	30
VII		96	15	15	15	12	35	25
VIII		160	16	14	18	14	40	40
IX		128	16	12	16	12	35	30
X		128	16	18	16	12	35	35
XI		128	16	14	18	16	40	35
1	69 85	143 160	17.6 24	14.4 22	17.4 24	14.2 22	37.3 45	32.7 45
2	123:123:100	112:090:100	136:136:100	153:153:100	138:126:100	155:155:100	120:120:100	138:138:100
4			109:100 122:100 109:100		100:100 122:100 109:100		100:100 114:100 100:100	
5			051 : 046 : 051 :		049 : 045 : 051 :		100 100 100	
6			250:100 312:100 312:100	272:100 347:100 272:100	250:100 305:100 291:100	250:100 365:100 272:100	267:100 271:100 267:100	267:100 306:100 267:100

TABLE IV. Test Results for Elevator Control

(Control-stick forces in kilograms)

	S t a t i c								
	R i g h t - h a n d e d			L e f t - h a n d e d			T w o - h a n d e d		
	Pull		Push	Pull		Push	Pull		Push
No.	Attached ErPa	Free ErPf	Attached Erpa	Attached ElPa	Free ElPf	Attached Elpa	Free EbPf	Attached EbPa	Attached Ebpa
I	60	65	60	55	65	55	83	120	120
II	60	90		55	75		82	112	115
III	55	70	45	55	60	50	87	107	
IV	50	65	50	50	70	55	84	102	90
V	50	65	56	45	55	55	72	92	95
VI	45	55	50	50	60	60	76	92	85
VII	45	60	40	50	60	40	72	87	100
VIII	75			60	80				
IX	65			70	70				
X	55			45	80				
XI	45			45	60				
1	55 75	67 90	50 60	53 70	67 80	52 60	79 87	102 120	100 120
2	136:109:100	134:097:100	120:120:100	132:104:100	120:097:100	116:106:100	110:105:100	118:118:100	120:120:100
3	093:100 082:100 083:100			085:100 079:100 087:100			145:100 129:100 139:100		
4	100:100 110:100 125:100			100:100 102:100 116:100			100:100 102:100 100:100		
5	050 052 056		:	046 052 054		:	100 100 100		

TABLE V. Test Results for Aileron and Rudder Controls
(Control-stick forces in kilograms)

No.	Aileron Control — Static — Right-handed — Pull — Attached ArPa	Pull — Free ArPf	Push — Attached Arpa	Push — Free Arpf	Left-handed — Pull — Attached AlPa	Pull — Free AlPf	Push — Attached Alpa	Push — Free Alpf
I	17	44	26	40	17	48	24	47
II	16	37	24	46	16	37	24	34
III	14	40	20	40	16	48	28	48
IV	18	25	26	22	18	26	24	23
V	16	33	18	34	16	30	18	40
VI	18	36	20	38	18	33	18	34
VII	14	29	14	29	14	28	14	24
VIII								
IX								
X								
XI								
1	16.1 18	34.9 44	21.1 26	35.6 46	16.4 18	35.7 48	21.4 28	36 48
2	112:106:100	126:126:100	124:124:100	129:113:100	110:104:100	135:135:100	131:112:100	133:130:100
3	039:100 046:100 041:100		065:100 059:100 057:100		036:100 046:100 038:100		051:100 059:100 058:100	
4	065:100 076:100 069:100	110:100 098:100 096:100			071:100 076:100 064:100	102:100 099:100 106:100		

TABLE V. Test Results for Aileron and Rudder Controls (cont.)
(Control-stick forces in kilograms)

	Aileron Control						Rudder control	
			Dynamic	Fatigued			Static	Fatigued
	Two-handed		Right-handed	Rt-handed	Lt-handed	Two-handed		
			Push(quick)	Pull				
No.	Attached Aba	Free Abf	Free Arpj	Free ArPft	Free AlPft	Free Abt	R	Rt
I	30	48	36	7	6	10	225	60
II	30	46	45	5	4	8	275	70
III	26	44	45	8	6	10	250	70
IV	26	36	36	3	3	8	200	50
V	24	42	27	5	5	8	225	80
VI	26	38	45	5	5	10	175	60
VII	20	30	36	4	3	7	200	50
VIII				6	5	10	225	80
IX				5	5	8	175	70
X				6	5	8	200	80
XI				8	6	10	250	70
1	26 30	40.6 48	38.4 45	5.64 8	4.82 6	8.84 10	218 275	67 80
2	116:116:100	118:118:100	117:094:100	142:124:100	125:125:100	113:113:100	126:103:100	120:090:100
3	063:100 064:100 063:100							
4	10 Stat.:Dyn.		111:100 092:100 102:100					
5	069:072:100 072:072:100 076:073:100	095:092:100 087:088:100 096:098:100				070:060:100 064:055:100 080:060:100		
6				630:100 620:100 550:100	800:100 740:100 800:100	480:100 460:100 480:100	373:100 325:100 344:100	

TABLE VI. Hand Forces and Quickness - (I = initial value. F = final value)

Hand forces (kg)

No.	ErPa		Erpt		ElPt		Elpt		EbPt				Ebpt				ArPt		AlPt		AbPt			
	I	F	I	F	I	F	I	F	I		F		I		F		I	F	I	F	I		F	
									r	l	r	l	r	l	r	l					r	l	r	l
I	54	45	53	48	50	45	54	46	49	46	42	41	53	55	45	43	55	52	52	48	55	52	51	49
II	69	61	71	69	63	59	60	57	70	65	50	47					65	67	58	55	64	58	60	58
III	52	32	58	52	45	34	51	38	49	40	35	29	50	42	52	45	52	56	51	50	55	44	47	42
IV	52	42	52	51	42	35			48	42	42	32	55	50	57	52	51	45	42	43	52	51	53	53
V	58	56	53	51	52	48	50	47	56	44	51	42	60	48	55	50	52	51	47	45	57	49	54	48
VI	50	45	50	42	42	30	42	38	49	43	46	41	48	43	47	45	47	46	45	42	48	41	48	42
VII	46	44	44	41	36	30	34	30	48	35	44	33	49	36	44	34	44	43	35	34	44	31	41	30
VIII	61	61	63	63	60	55	58	56	61	59	54	50	57	57	64	60	62	65	62	60	60	58	59	58
IX	57	55	57	55	49	47	44	46	61	51	58	49	61	52	61	51	63	65	47	47	57	54	55	52
X	50	49	51	50	45	42	44	42	54	46	51	47	53	48	42	38	51	47	50	49	48	48	48	45
XI	51	52	45	46	48	48	50	50	51	48	49	47	60	54	58	52	55	53	54	52	58	55	59	54
8	54.5	49.3	54.3	51.6	48.4	43.0	48.7	45.0	54.2		47.5		54.6		52.5		54.3	53.6	49.4	47.7	54.4		52.3	
	% weakening																							
8	9.5		5.0		11.1		7.6		12.3				3.5				1.3		3.4		2.9			

Quickness (cm/s)

No.	Elevator control: Maximum force (kg) 0	32	64	96	128	160	Rudder control: Maximum force (kg) 0	9	18	27	36	45
I	210	210	210	200	190	0	190	190	185	200	175	0
II	210	210	210	210	250	280	175	175	175	175	175	175
III	210	200	190	180	220	250	180	200	180	180	185	170
IV	200	180	175	175	175	175	175	175	175	175	150	0
V	200	210	210	250	0	0	175	175	175	175	175	0
VI	150	175	175	175	160	170	200	195	200	200	195	205
VII	200	175	175	175	190	170	145	135	145	125	0	0
VIII	210	210	200	200	210	190	200	190	185	200	200	190
IX	175	175	175	150	160	0	175	175	175	170	170	0
X	210	175	175	175	200	0	145	145	150	150	150	160
XI	170	175	175	200	175	0	200	200	200	200	190	200
11	195	191	188	190	193	(206)	178	178	177	177	176.5	(184)

TABLE VII. Test Results with Wheel Control.

The values are dynamometer readings D in kilograms. From them we get the force R of one hand by the formula

$$R = \frac{D\,r}{d} = \frac{1}{7.2}\,D\ \text{(kg)}$$

The turning moment is

$$M = D\,r = D\,5\ \text{(kg-cm)}$$

Test subjects						45° right, up		45° left, up				
No.	Height cm	Weight kg	Age	Vocation	Interest in sports	Turn r	Turn l	Turn r	Turn l	Horizontal	Vertical	Unforced maximum force
1	172	80	24	Engineer	Much	250	200	220	205	220	200	200
2	173	80	25	"	"	250	200	220	205	220	220	150
3	164	75	27	"	"	200	170	220	160	220	215	150
4	187	70	28	"	Little	210	150	245	160	200	200	100
5	-	-	38	Aviator	Average	210	125	220	175	185	200	150
6	170	78	19	Student	Much	205	110	175	150	200	170	150
7	175	78	23	Engineer	Average	200	165	170	130	150	175	100
8	172	80	26	"	"	200	170	155	130	160	150	125
9	168	65	37	Carpenter	Little	175	140	145	140	150	145	100
10	183	73	27	Engineer	"	155	160	155	125	140	130	100
Mean value						205	159	193	158	184	180	133
Maximum value						250	200	245	205	220	220	-
Maximum value/mean value						122:100	126:100	127:100	130:100	120:100	122:100	-

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

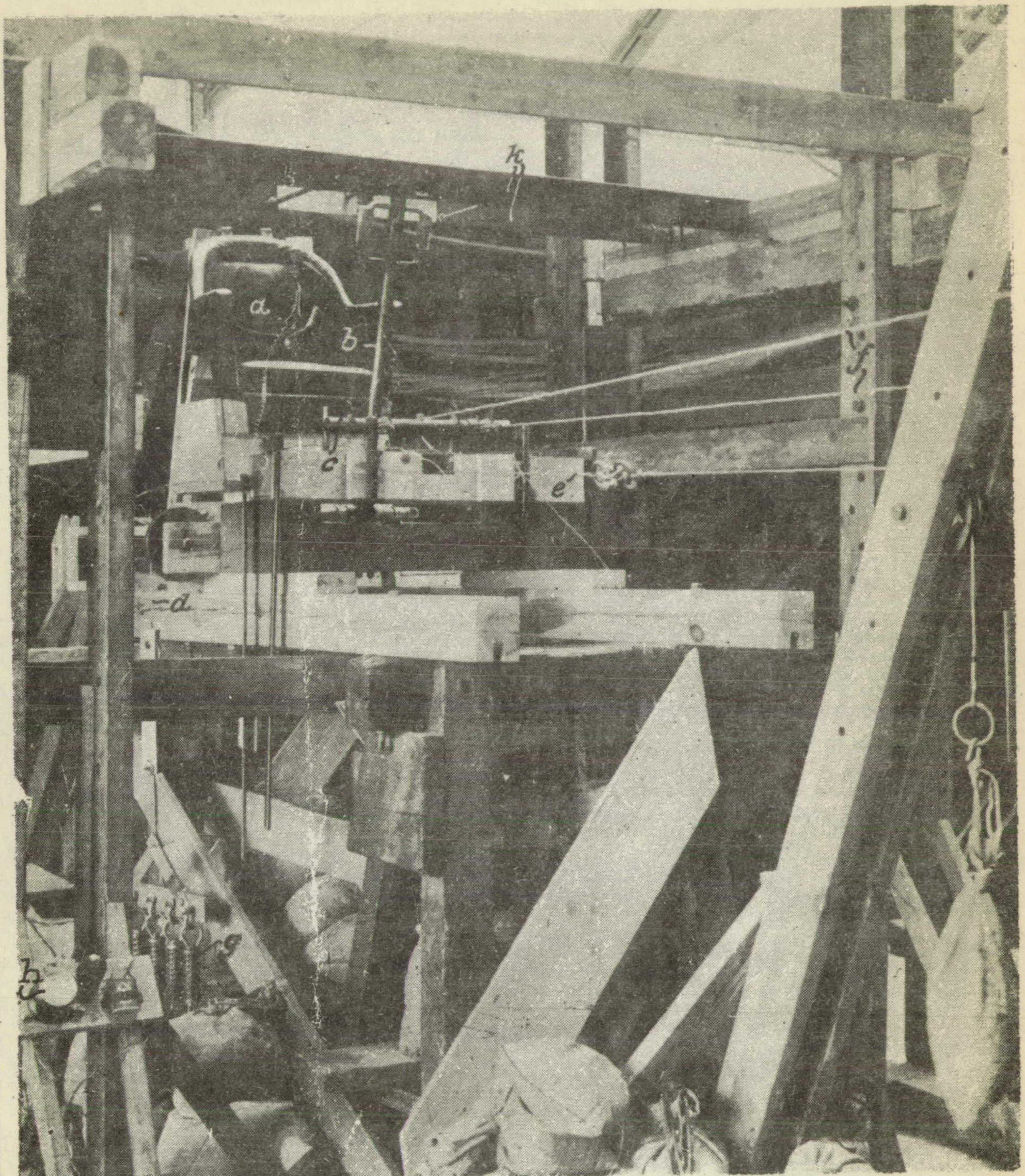

Fig. 1 Test outfit

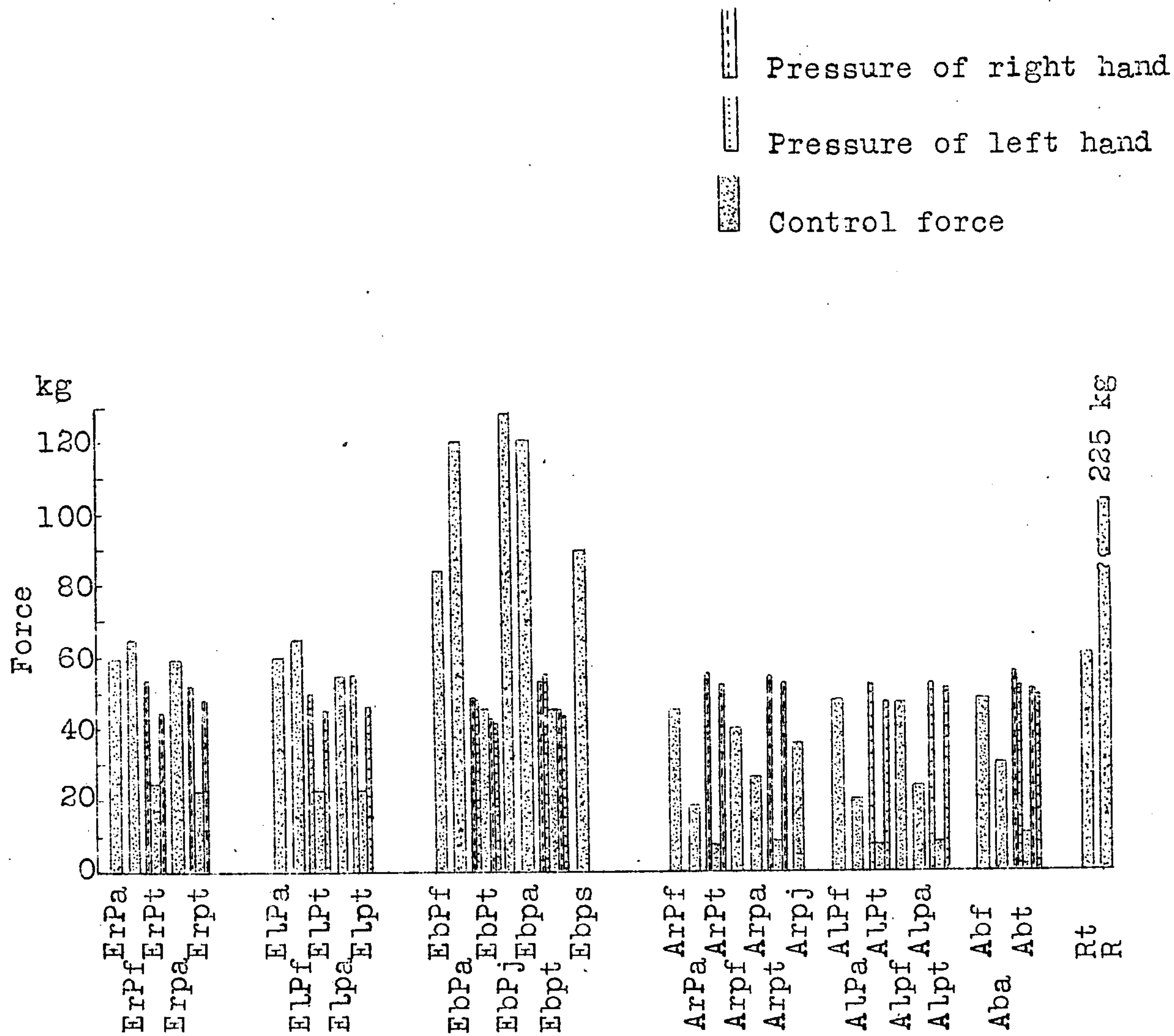

Fig.2 Results of tests with chief subject.

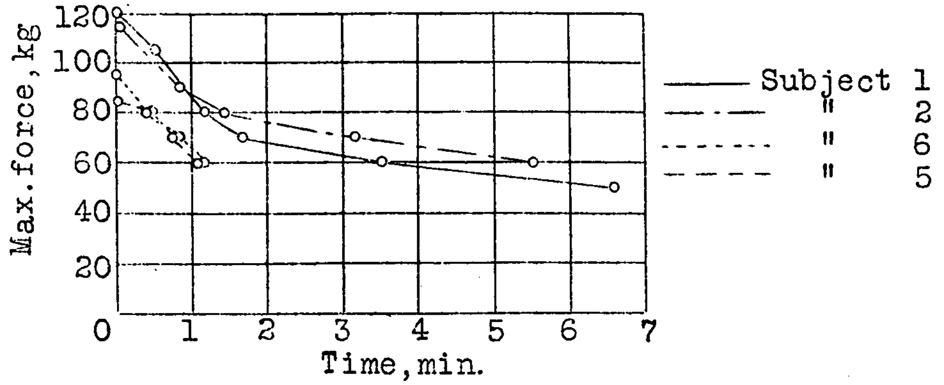

Fig.3 Maximum force plotted against time held. (Two-handed push.)

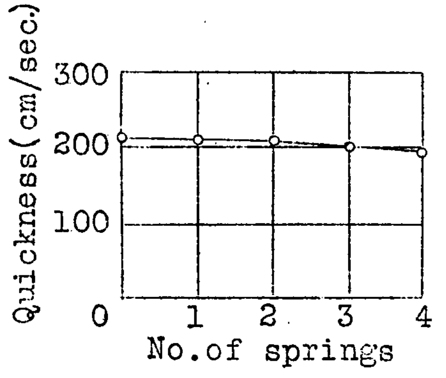

Fig.4 Elevator-quickness tests with chief subject.

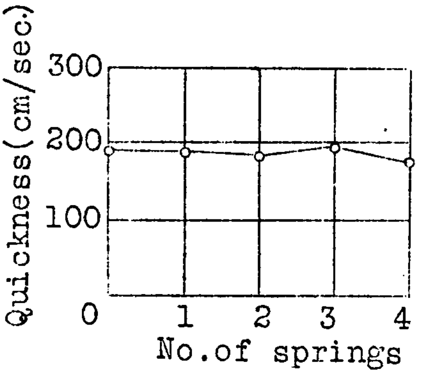

Fig.5 Aileron-quickness tests with chief subject.